SAFE DECOMMISSIONING OF THE ROMANIAN VVR-S RESEARCH REACTOR

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Abstract. The VVR-S Romania research reactor was operated between 1957-1997, at 2 MW nominal power, for research and radioisotopical production. The detailed decommissioning plan was developed between 1995-1998, in the frame of the International Atomic Energy Agency Technical assistance project ROM/9/017. The proposed strategy agreed by the counterpart as well as international experts was stage 1. In 1997, an independent analysis performed by European Commission experts, in the frame of PHARE project PH04.1/1994 was dedicated to the "Study of Soviet Design Research Reactors", had consolidated the development of the project emphasizing technical options of safe management for radioactive wastes and VVR-S spent fuel. The paper presents the main technical aspects as well as those of social impact, which lead to the establishment of strategy for safe management of decommissioning. Technical analysis of the VVR-S reactor and associated radwaste facilities (Radioactive Waste Treatment Plant – Magurele and National Repository Baita-Bihor) proved the possibility of the classical method utilization for dismantling of the facility and treatment-conditioning-disposal of the arrised wastes in safe conditions. The decommissioning plan at stage 2 has been developed based on radiological safety assessment, evaluation of radwaste inventory (removed as well as preserved on site), cost analysis and environmental impact. Technical data were provided by the R&D programme including neutron calculations and experiments, radiological characterizing (for facility and its influence area), seismic analysis and environmental balance during the operation and after shut down of the reactor. A special chapter is dedicated to regulatory issues concerning the development of decommissioning under nuclear safety. Based on the Fundamental Norms of Radiological Safety, the Regulatory Body defined the clearance levels and safety criteria for the process. The development of National Norms for the decommissioning of research reactors and other small nuclear facilities as well as for restoration of sites damaged by nuclear activities, is in progress. The correct information of the public regarding decommissioning using advanced methods provides the necessary transparency.

INTRODUCTION

Decommissioning of nuclear installations requests preparatory actions by the owner as well as by the state authorities (e.g. Regulatory Body, local county government, environmental and health protection inspectorates etc.) involved. This work includes:

- a research programme defined as a scientific support for necessary technical developments of the project;
- elaboration of the detailed decommissioning plan [1];
- preparation of the support studies referring to the facility *as built* report, safety case, environmental impact, quality assurance (QA) and radiological safety report; and
- development of the physical protection arrangements.

Specific nuclear technologies for dismantling as well as techniques for safe treatment-conditioning disposal of radioactive waste from decommissioning, must be designed according to the proposed strategy of the project [2].

Taking into account that the VVR-S Romania research reactor (in permanent shut-down since December 1997) is the first assembly under decommissioning, the Romania Regulatory Body has to create the legal framework of the process.

RADIOACTIVE INVENTORY OF VVR-S ROMANIA RESEARCH REACTOR

Activation inventory

The radioactive inventory due to activation has been established by neutron calculations using one- and two-dimensional codes (e.g. ANISN, WIMS, DORT). The obtained neutron flux distributions, collapsed in 3 energy groups, have been used as input data for ORIGIN code.

Neutron measurements have been performed in order to validate calculation results for the reactor core, reflector, water and concrete biological shielding. The absolute fission rates, measured by means of miniature fission chambers, Saclay type, have been used to determine neutron flux spectra by the SAND II unfolding code.

These flux spectra, 620 energy groups, have been broken into 3 energy groups for comparison with calculation results. Calculation results have been adjusted taking into account the values obtained by measurements performed on the horizontal middle plane of the core.

The radioactive inventory is presented in Table 1. There are given radioactive waste masses of aluminum, steel, concrete and graphite, divided on the LLW (low level waste), MLW (medium level waste) and HLW (high level waste) categories. The activities (in Ci) have been calculated for 3, 15, 25 and 50 years from permanent shutdown.

Table 1 RADIOACTIVE WASTE FROM VVR-S RESEARCH REACTOR

MATERIAL	LEVEL	3 years		10 years		25 years		50 years	
		Mass (kg)	Activity (Ci)	Mass (kg)	Activity (Ci)	Mass (kg)	Activity (Ci)	Mass (kg)	Activity (Ci)
ALUMINUM	HLW	8.12E+00	3.78E+00	5.15E-01	2.11E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	MLW	2.64E+03	3.34E+01	2.32E+03	7.81E+00	1.67E+03	2.55E+00	1.24E+03	1.92E+00
	LLW	1.03E+03	7.28E-05	1.25E+03	7.24E-05	1.48E+03	8.15E-05	1.26E+03	5.30E-05
	TOTAL	3.67E+03	3.71E+01	3.57E+03	8.02E+00	3.15E+03	2.55E+00	2.50E+03	1.92E+00
STEEL	HLW	1.97E+03	1.35E+03	8.13E+02	1.45E+02	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	MLW	8.02E+04	2.75E+02	7.68E+04	1.19E+02	6.19E+04	1.47E+01	4.55E+04	7.39E+00
	LLW	2.11E+03	1.48E-04	6.64E+03	2.98E-04	2.24E+04	6.81E-04	3.88E+04	1.44E-03
	TOTAL	8.43E+04	1.62E+03	8.43E+04	2.65E+02	8.42E+04	1.47E+01	8.42E+04	7.39E+00
CONCRETE	HLW	1.10E+02	5.37E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	MLW	2.78E+04	1.76E+02	1.21E+04	3.56E+01	7.86E+03	6.94E-01	5.60E+03	4.25E-02
	LLW	3.22E+04	8.36E-04	4.81E+04	2.07E-03	3.20E+03	2.20E-04	2.24E+04	1.26E-04
	TOTAL	6.01E+04	2.29E+02	6.03E+04	3.56E+01	1.11E+04	6.94E-01	2.79E+04	4.26E-02
GRAPHITE	HLW	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	MLW	1.16E+03	1.57E-02	1.16E+03	1.57E-02	1.16E+03	1.56E-02	1.16E+03	1.56E-02
	LLW	2.77E+03	3.74E-04	2.77E+03	3.74E-04	2.77E+03	3.73E-04	2.77E+03	3.72E-04
	TOTAL	**3.93E+03**	**1.61E-02**	**3.93E+03**	**1.61E-02**	**3.93E+03**	**1.60E-02**	**3.93E+03**	**1.60E-02**
TOTAL		**1.52E+05**	**1.89E+03**	**1.52E+05**	**3.08E+02**	**1.02E+05**	**1.79E+01**	**1.19E+05**	**9.37E+00**

HLW - specific activity greater than 10^{-3}Ci/cm^3

MLW - specific activity greater than 10^{-9}Ci/cm^3 and lower than 10^{-3}Ci/cm^3

LLW - specific activity greater than 4×10^{-13}Ci/cm^3 and lower than 10^{-9}Ci/cm^3

Impurities in structure materials

The main structures of the VVR-S Romania research reactor have been made in aluminum and iron, the biological shielding being made in concrete. The long life impurities in these materials lead to a significant increase of radioactive inventory. These impurities have been determined by neutron activation method. The following amounts of impurities are contained in:

Aluminum	0.30 ppm cobalt
	1107 ppm iron
Iron	43 ppm cobalt
Concrete in thermal column shielding	3.9 ppm cobalt
	1.1% iron
Concrete in pump room	5.6 ppm cobalt
	1.5% iron

The calculated radioactive inventory has been amended taking into account this impurity determination [3].

DECOMMISSIONING STRATEGY

The strategy was defined and submitted for approval by Romanian specialists and international experts of the IAEA, in the frame of the Technical Assistance Project ROM/9/017, IAEA, in the document "Decommissioning Plan of VVR-S IFIN-HH Research Reactor". A final review of the decommissioning strategy is also enclosed in the report made by a common team of experts from the European Commission and Romania.

The strategy established for the reactor decommissioning up to stage 2 presumes:

- removal from the reactor building of nuclear spent fuel and its store in ponds, outside in a special dedicated deposit named Nuclear Spent Fuel Deposit (DCNU – Romania);
- removal of all research equipment and operation tools in the reactor hall and technological areas;
- decontamination of the reactor vessel as well as the spent fuel cooling pond in reactor hall and primary circuit;
- dismantling of the primary circuit;
- dismantling of internal components of the reactor;
- hot cells decommissioning;
- decommissioning of the spent fuel cooling deposit (at reactor);
- decontamination of technological areas;
- auxiliary circuits decommissioning (active drainage system, supplies of water as well as compressed air);
- decommissioning of supply systems, thermal and electric power, as well as of the control system and its associated automatics); and
- decommissioning of the secondary circuit (uncontaminated).

In accordance with the above proposed strategy, the following reactor components should not be dismantled:

- main reactor block (heavy concrete);
- reactor vessel (aluminum);
- intermediary vessel (aluminum);
- separator and fuel support grid (aluminum);
- cast iron shielding (iron);
- reactor lids (iron); and
- vertical channels welded by main reactor vessel (aluminum).

All these components give medium and high radioactivity wastes (MLW and HLW).

RADIOLOGICAL CHARACTERIZATION

After 40 years of reactor operation there are high radioactivity wastes stored in vertical channels of biological shielding. More than 70 radioactive experimental devices were characterized, by dose rate and radioisotopic composition measurements.

The same types of measurements have been used in order to characterize more than 500 objects from research, stored in the reactor hall.

The technological areas of the reactor have been characterized during its operation (1996) as well as after its permanent shut down (1998). After the reactor's permanent shut down each technological area was scanned for determination of surface contamination as well as γ dose rate. The specific γ contaminants have been determined in 34 technological rooms (6 rooms were not available) [4].

In the areas with surface contamination exceeding limits for nonrestrictive release, a special sampling in the contaminated concrete, following in-depth contamination determination was performed. The sampling depths are 1, 2, and 3 cm, in four places selected by physical characterization of concrete as well as the contamination level. The measurements made by high resolution spectrometry (the instrument being absolutely calibrated) show contamination with ^{60}Co in Reactor Hall as well as ^{60}Co and fission products ^{137}Cs, ^{134}Cs, ^{69}Zn in the room of primary circuit pumps. Their activities exceed the limits for nonrestrictive releasing [5].

The radiological characterizing works have been extended outside the reactor building in order to establish the radiological status of waste and spent fuel routes. A special programme of measurements has been performed in order to define the influence of nuclear activities in the area of the Reactor – Spent Fuel Storage – Radioisotope Production Center – Radioactive Waste Treatment Plant. The vegetation and soil samples have been taken in 18 points of the above mentioned area. These samples have been measured in the lab. The γ dose rate and surface contamination have also been determined in 120 places in the same area [6].

DECONTAMINATION ACTIVITIES

During decommissioning, decontamination is used to reduce radiation doses and the risk of spread of contamination by removing a part of the activation and fission products contained in deposits, oxidation films and dust in the facility to minimize radiation exposure, following the ALARA principles. Other reasons for decontamination include recovery of a valuable material if free release can be achieved and/or compliance with the radioactive wastes treatment and repository requirements. In decommissioning, reduction of the residual contamination is an important objective regardless of whether or not free release is achieved.

Concerning decontamination activities, the following subjects were treated in the decommissioning plan:

- Selection of a decontamination method or process
- Decontamination methods
- Chemical decontamination processes
- Non-chemical decontamination processes
- Selection of the proposed processes

In the primary reactor system, the contamination of the internal surfaces is a result of the corrosion products deposition including neutron activation radionuclides, fission products and transuranic elements released from fuel.

For the VVR-S reactor preconstruction oxides are presumed to be composed mainly of Al^{3+}, Fe^{3+}, Fe^{2+} and Cr^{3+}.

For the decontamination of the primary circuit, based on experience from similar reactors in neighboring states (Germany, Hungary, Czech Republic), a three-cycle process at room temperature is proposed:

Cycle **A.**	nitric acid	0.25 – 3.00 g/l
	potassium permanganate	1.00 – 5.00 g/l
Cycle **B.**	nitric acid	1.50 – 5.00 g/l
	oxalic acid	1.50 – 4.00 g/l
Cycle **C.**	citric acid	1.00 – 2.00 g/l
	oxalic acid	0.50 – 1.00 g/l
	potassium hydroxide	0.40 – 1.50 g/l

The expected decontamination factor (DF) is between 5 to 15, permitting normal working conditions during the disassembling activities. For any decontamination performed at the dismantling location and in the RWTP for each type of surface, a preliminary laboratory testing programme will permit the selection of the most appropriate procedures.

RADWASTE IN VVR-S DECOMMISSIONING

Dismantling

Based on the proposed strategy (2-stage IAEA) we can define the radioactive waste categories:

- historical waste that arose from the VVR-S Romania reactor operation as well as research programmes;
- waste from the dismantling of the control system;
- waste from the main equipment and pipes in primary circuit;
- waste from the hot cells (equipment, tools, etc.).

The most important amount of waste is generated by the dismantling of the primary circuit (47 tons stainless steel; 3.7 tons carbon steel). The equipment in hot cells will provide 3 tons of stainless steel as well as 2.5 tons carbon steel. The secondary wastes from decommissioning are caused by primary circuit decontamination, ranging between 120 up to 360 m^3 liquids, for 1 to 3 cycles. The wastes from ion resin exchangers are between 1 and 5 m^3.

All these wastes have low activity. The high activity wastes arose from dismantling of reactor control system (e.g. control rods and their associated channels) and irradiation channels. There are elaborate dismantling procedures up to stage 3 of decommissioning. The expertise of the older workers participating in the mounting of this facility was used for defining the technical issues in dismantling.

Treatment, conditioning and disposal of radioactive waste

Aqueous effluents coming from reactor are collected in a buffer tank placed near reactor building connected by tubes to Radioactive Waste Treatment Plant – Magurele (RWTP) ponds: 600 m^3 for LLW and 40 m^3 for MLW. The existing system treats 27 m^3 load of wastes. The main treatment procedures are:

- chemical treatment;

- evaporation;
- passing the distillate trough ion exchange resin column.

After treatment, collected precipitate undergoes more chemical operations, it is pumped in a concrete mixing system and sealed in concrete, in containers for long term storage (disposal).

Combustible solid radwaste is burned in an incinerator, the gases are filtered and the ash is collected and cemented. The solid radwste, which cannot be compacted is directly cemented in standard drums.

The solid waste, evaporation precipitate and radioactive ash are conditioned by cementing in 200 liter drums. It would be suitable that the solid radwaste from reactor decommissioning to be conditioned in flasks with volumes greater than 200 liter, in order to reduce the costs of large equipment segregation.

The country is provided with a radwaste National Repository Baita-Bihor legally commissioned for LLW and MLW.

RADIATION PROTECTION AND SAFETY PROGRAMME

The safety case for decommissioning

The Safety Case is a series of statements, claims and objectives which will ensure that the entire decommissioning process is conducted in a safe and orderly manner [7,8,9]. The content of this safety case for the VVR-S Romania research reactor was established according to the Romanian Regulatory Body preliminary agreement.

The safety case for the VVR-S decommissioning project will state at least the following:

1. The risks to the public and the environment will be kept as low as reasonably achievable at all times. (This usually means radiological risks which is strictly controlled by the Regulations.)
2. The risks to workers will be kept as low as reasonably achievable commensurate with the tasks they have to perform (This will inevitably be slightly higher than for the public and this is recognized in the Regulations. Risks will involve radiological and industrial hazards.) [10].
3. Adequate planning is or will be done for all decommissioning processes and must be agreed by Regulator (CNCAN). Dismantling activities will be done in carefully controlled steps to allow the Regulator to approve operations or prevent any unsafe procedures.
4. The management of all decommissioning wastes will be carefully controlled and appropriate storage arrangements will be made until a disposal route is available.
5. Arrangements to limit the spread of contamination will be enforced by procedures and the necessary equipment.
6. Surveillance, inspection and monitoring of the plant and facilities will be done and reported on at regular intervals.
7. Assessment of all significant fault conditions and hazards will be undertaken and all necessary counteractive and mitigating measures will be taken or put in place.
8. Emergency plans will be formulated to ensure that all abnormal conditions or accidents are adequately coped with.
9. Appropriate QA procedures and document control measures will be instituted. This will include adequate training.

Legal framework

In Romania, nuclear activities are regulated by Law No.111/1996 (republished) regarding the "Safe deployment of nuclear activities". Regulation aspects of the VVR-S Romania research reactor are related to:

- elaboration of the General Norm for Decommissioning of Research Reactors and Other Small Nuclear Facilities;

- authorizing of the VVR-S Romania research reactor decommissioning stages based on Regulatory Body provisions and dispositions.

In this respect the following points are requested:

- justification of the preferred decommissioning option;
- demonstration of the financial capability of the facility owner to finalize the process;
- overall scheduling of the decommissioning activities up to free release;
- correlation of the clearance levels (conditioned or unrestricted) with the authorizing limits in the frame of the license.

The radioprotection programme was defined on the basis of the Fundamental Norms of Radiological Safety (2000), in force in the country.

The environmental protection is managed under the provisions of Law No.137/1995.

COST AND SCHEDULING

Cost assessment of decommissioning was performed at the level of 1996, within the frame of Technical Assistance Project ROM/9/017 IAEA Vienna, by the code "Cost Estimating Computer Programme", adapted for research reactors by Dr. R.I.Smith (USA) as well as by method "Spreadsheet Approach" by Dr. J.Fitzpatrick (UK). The cost obtained by the first method is 3.4 million US$. The second method gave a cost of 2.24 million US$. These calculations did not consider the costs for:

- the works at reactor building needed for decommissioning;
- the equipment and instrumentation used in decommissioning operations; and
- the equipment for dosimetric surveillance and control.

The difference in cost evaluation for the above mentioned are due to the different costs of proposed equipment as well as the level of details in information available in 1996.

CONCLUSIONS

1. The detailed decommissioning plan is completed, but it is necessary to be updated after 4 years;
2. The legal framework of the country can assure the overall safe process of decommissioning up to stage 3: and
3. In order to implement the detailed decommissioning plan within the frame of the IAEA Technical Assistance Project ROM001/2003 it is mandatory to define technical procedures and to procure the equipment.

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